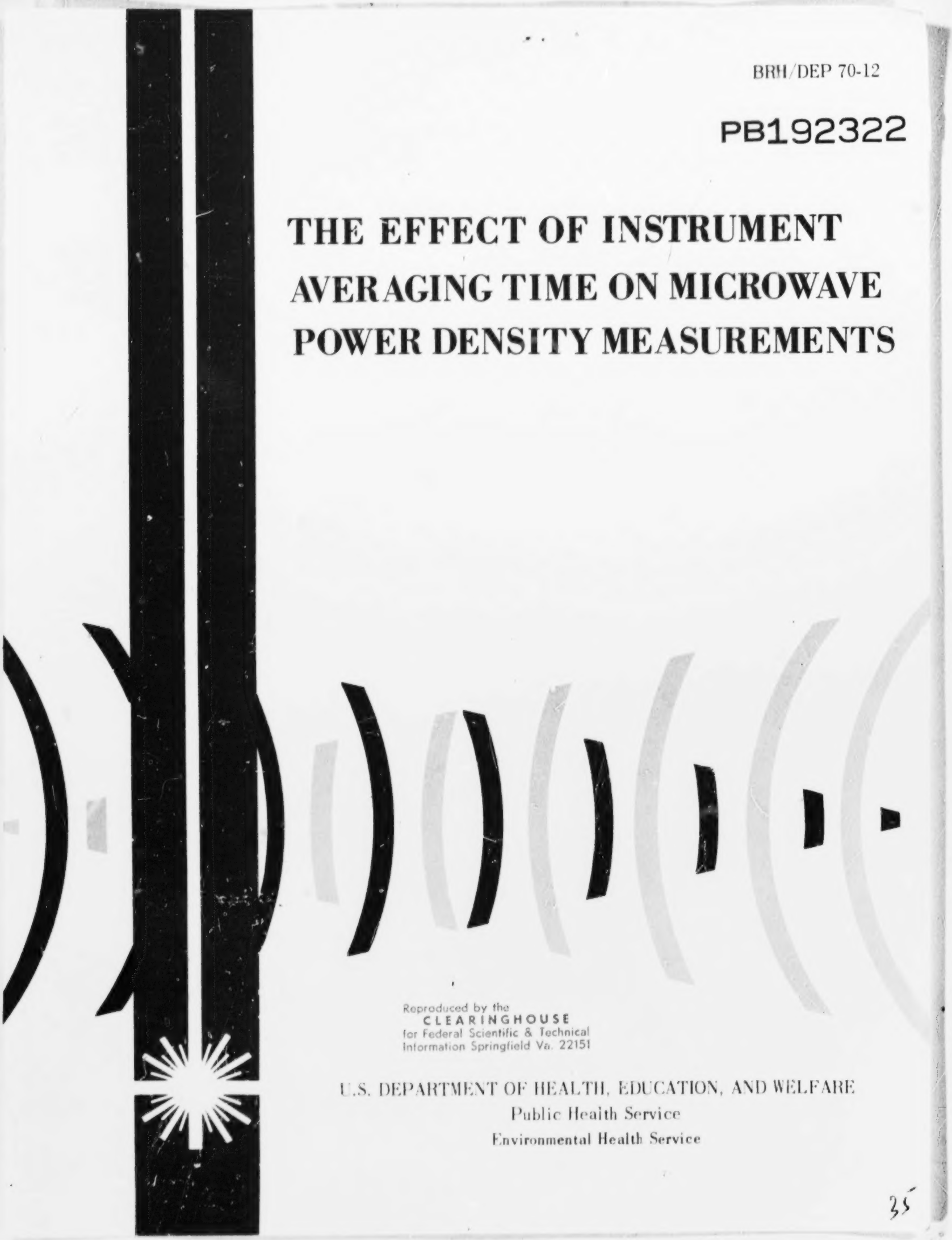
BRH/DEP 70-12

PB192322

THE EFFECT OF INSTRUMENT AVERAGING TIME ON MICROWAVE POWER DENSITY MEASUREMENTS



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DIVISION OF ELECTRONIC PRODUCTS

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BRH/DEP 70-12

THE EFFECT OF INSTRUMENT AVERAGING TIME ON MICROWAVE POWER DENSITY MEASUREMENTS

Radiation Measurements and Calibration Branch
Division of Electronic Products

June 1970

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Radiological Health
Rockville, Maryland 20852

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FOREWORD

The Bureau of Radiological Health, formerly the National Center for Radiological Health, continues to carry out a national program designed to reduce the exposure of man to hazardous ionizing and non-ionizing radiation.

Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training, development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

The Bureau publishes its findings in Radiological Health Data and Reports (a monthly publication), Public Health Service numbered reports, appropriate scientific journals, and technical report series for the Bureau's divisions, offices, and laboratories.

The technical reports of the Division of Electronic Products (DEP) allow comprehensive and rapid publishing of the results of intramural and contractor projects. The reports are distributed to State and local radiological Health program personnel, Bureau technical staff, Bureau advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

The Division of Electronic Products, Bureau of Radiological Health, as a part of its responsibility under the "Radiation Control for Health and Safety Act of 1968", conducts a program of evaluation of the effectiveness of procedures and techniques for minimizing exposure to radiation from electronic products. The present report considers the effect of instrument averaging time on recorded values of leakage from microwave ovens. The effect of instrument averaging time on measurement techniques is also considered.

The report includes the measurement of the response time of the Narda 8100 and a recommended procedure for the use of this instrument. Proposed procedures for implementing the performance standard for microwave ovens are evaluated.

Robert L. Elder, Sc.D.
Acting Director
Division of Electronic Products

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ABSTRACT

The response of the Narda 8100 system to a stepped input of microwave power was measured with a video tape recorder. The Narda 8100 was then used to measure variations in microwave power density due to "mode stirring". This report discusses the averaging effect caused by the response time of the instrument system on the observed power density. Examples of averaged values of power density from microwave ovens are included.

THE EFFECT OF INSTRUMENT AVERAGING TIME ON MICROWAVE POWER DENSITY MEASUREMENTS

INTRODUCTION

This report is a study of the response time of a particular microwave power density meter and the effect of its response on measurements taken of leakage from microwave ovens. It is intended that this report will aid Bureau of Radiological Health personnel in the development of procedures using this and similar instrumentation for the test of compliance of microwave ovens with the proposed performance standard under the "Radiation Control for Health and Safety Act of 1968" (Public Law 90-602).

The first portion of this report is devoted to effects of the response time of the measuring instrument on measurements. The response time of the Narda 8100 power density system was measured for fast and slow response settings. The effect of these response times on leakage measurements was then observed. The effect of mode stirring on radiated power density for various ovens and the effect of meter averaging as well as numerical averaging on the output from various mode stirrers is presented.

New microwave cooking ovens purchased by the Bureau of Radiological Health's Division of Electronic Products were involved in the testing. The Narda 8100 microwave measuring system was used for leakage measurements. This instrument, if used on the fast response setting, is acceptable for microwave leakage measurements from all microwave ovens now available on the commercial market. A five-centimeter spacer was used in all measurements taken. The appropriate probe spacer was used for the particular oven frequency being observed. In some cases a deliberate leakage condition was established to produce the desired power density for experimental conditions. This was accomplished by putting several layers of Scotch filament tape between the oven and oven door.

Appendix A presents a recommended procedure for use of the Narda 8100 system to survey microwave ovens.

RESPONSE TIME OF THE NARDA 8100 SYSTEM

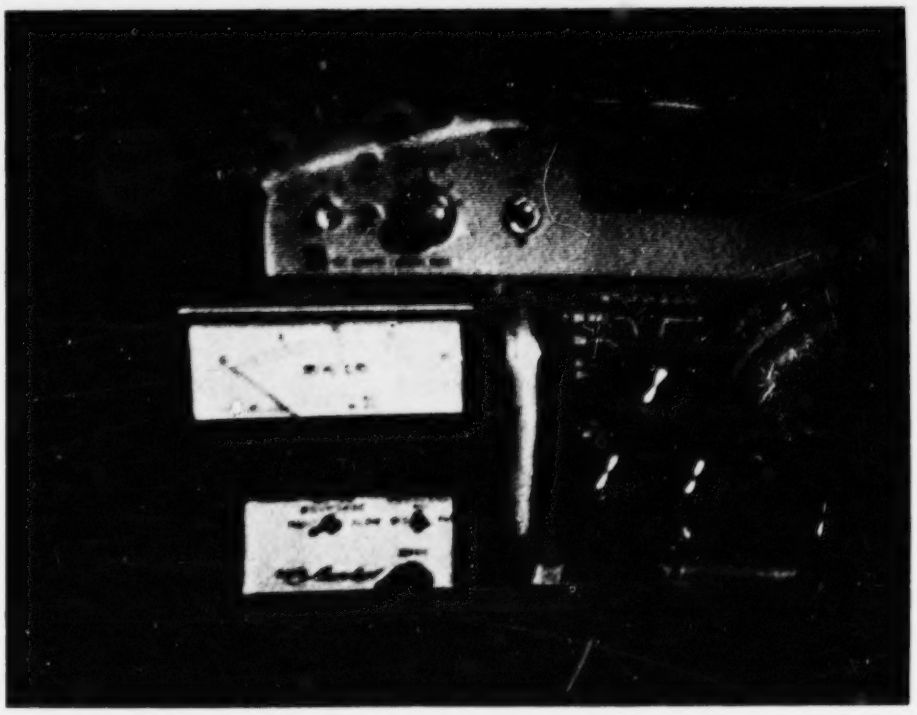
A great deal of confusion has existed concerning the meaning of the terms "response time" and "time constant" of a complex measuring system such as the Narda 8100. For example, the response of the Narda system will be due to the combined responses of the probe (antenna/detector) electronic circuitry and its meter. It is hoped that the observations presented in this report will not only help determine which of these will be the dominant factor but will aid in the understanding of the effect of instrument response time on measured values.

MEASUREMENT METHODS

The microwave source used for response measurements was a Polarad generator set to a frequency of 2450 MHz. The rise time of the output of this generator was measured to be less than 0.2 msec using a Tektronix 555 oscilloscope. The output of the generator was directly coupled to the Narda probe being used. By turning the RF power on or off, the system's response to the stepped input could be observed. The rise or decay time of the output of the generator was less than the response of the Narda system by more than three orders of magnitude. Thus the effect of rise and decay of the RF signal could be ignored.

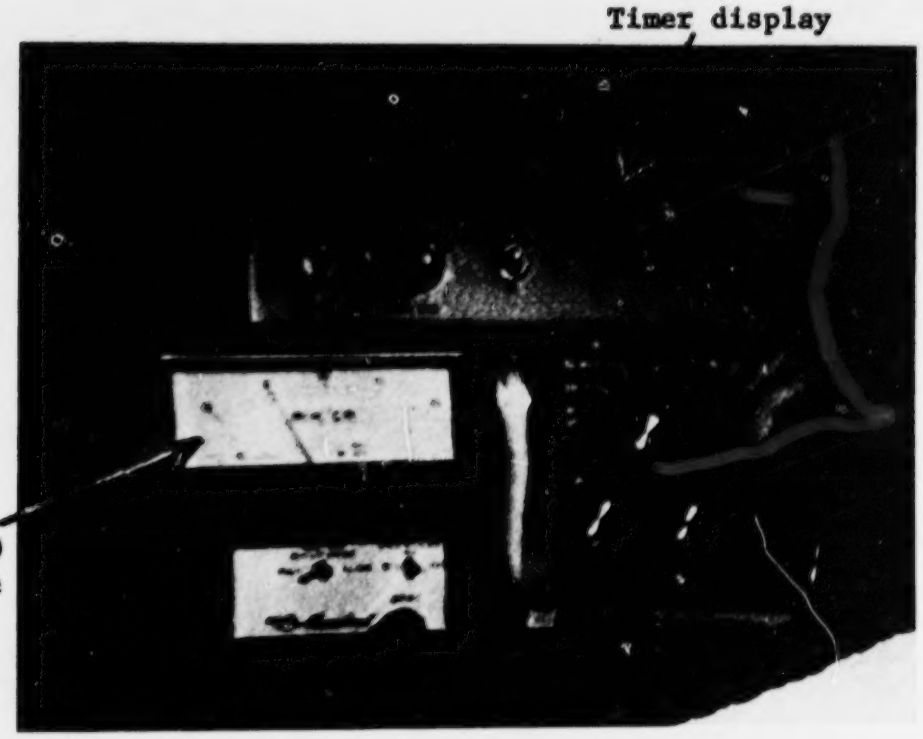
The Narda meter face, the on-off switch of the Polarad generator, and a General Radio 1191 counter used as a visual timer were placed in view of a closed circuit television system. A video tape was used to record subsequent events. Immediate viewing and frame by frame play back viewing were provided. Frame by frame play back allowed the recording of the time of an event within 0.02 second. (Note experimental arrangement shown in figure 1a.) The frame in which the power was turned on (figure 1b) was located and the start time was recorded. Subsequent timer and meter readings (figure 1c and 1d) could be obtained by locating the proper video frame.

a. Equipment layout.

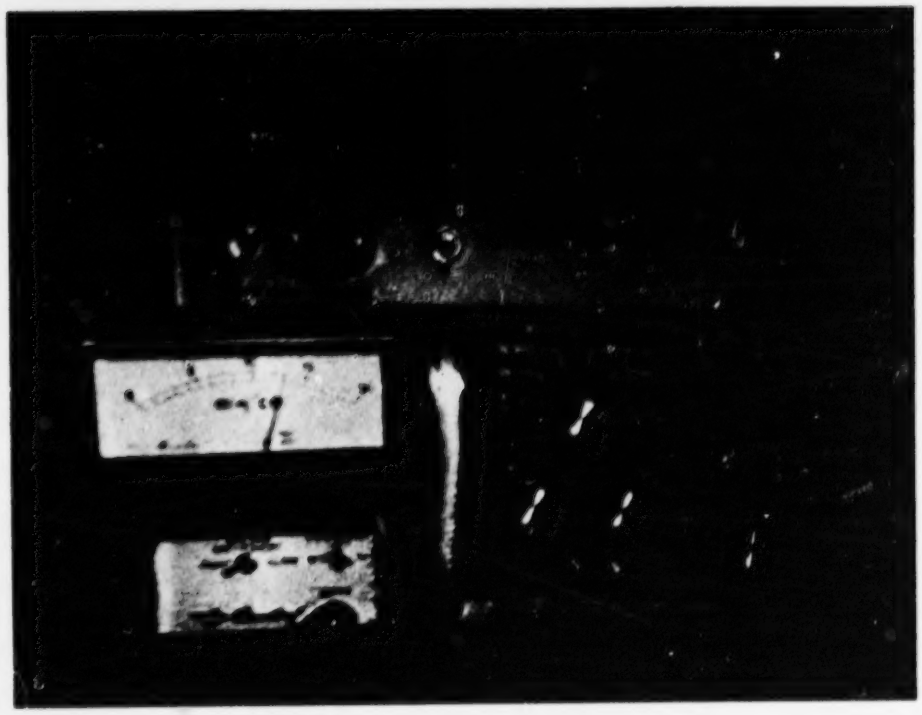


b. Establishment of starting time.

Figure 1. Experimental setup for measurement of response of the Narda 8100 system.



c. Point of data recording.



d. Point of data recording.

Figure 1. Experimental setup for measurement of response of the Narda 8100 system (continued).

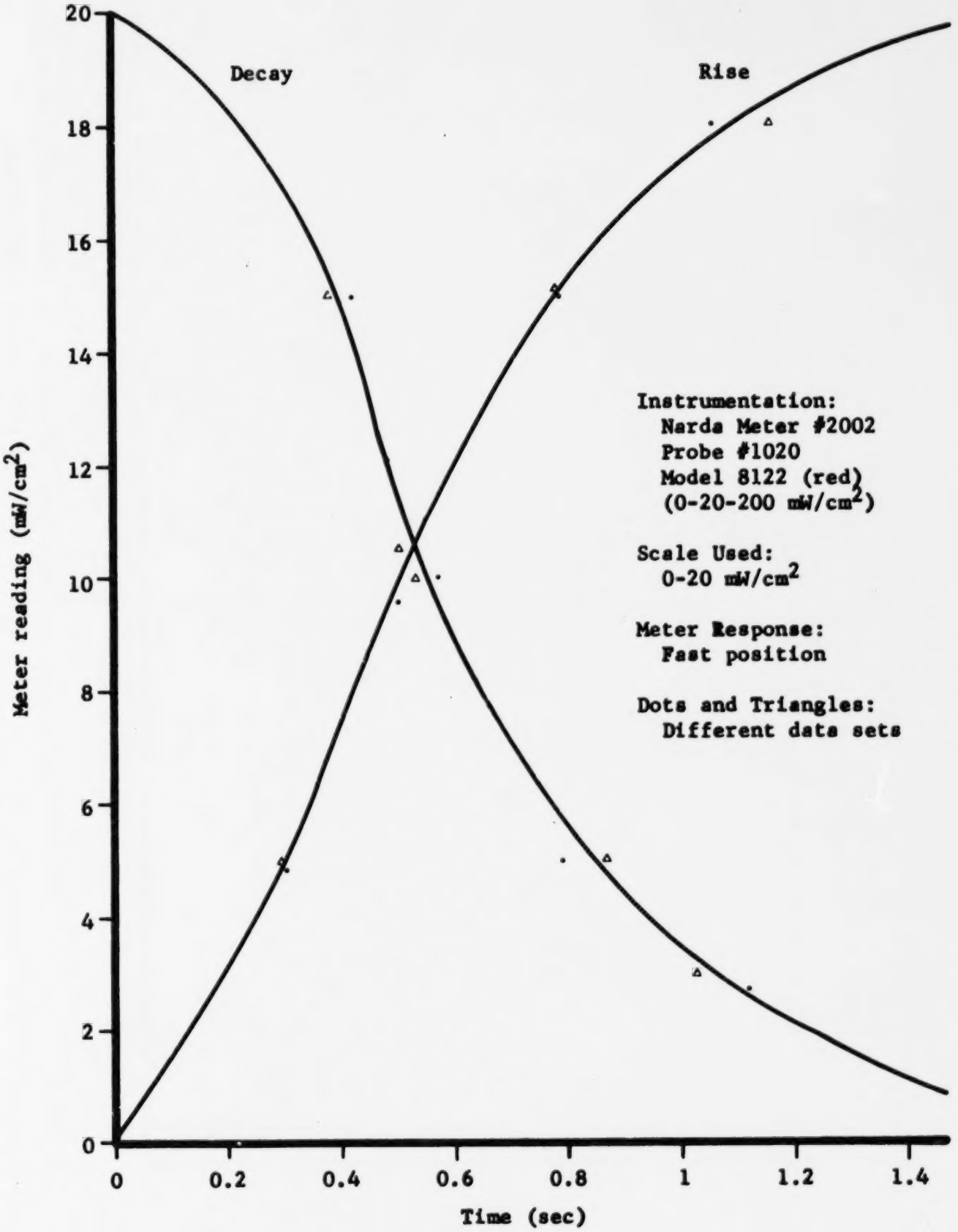


Figure 2. Fast response of Narda 8100 to stepped RF input, Model 8110-8122 combination.

Instrumentation: Narda Meter #2002
Probe #1020 Model 8122 (red)
(0-20-200 mW/cm^2)

Scale Used: 0-20 mW/cm^2

Meter Response: Slow position

Dots and Triangles: Different data sets

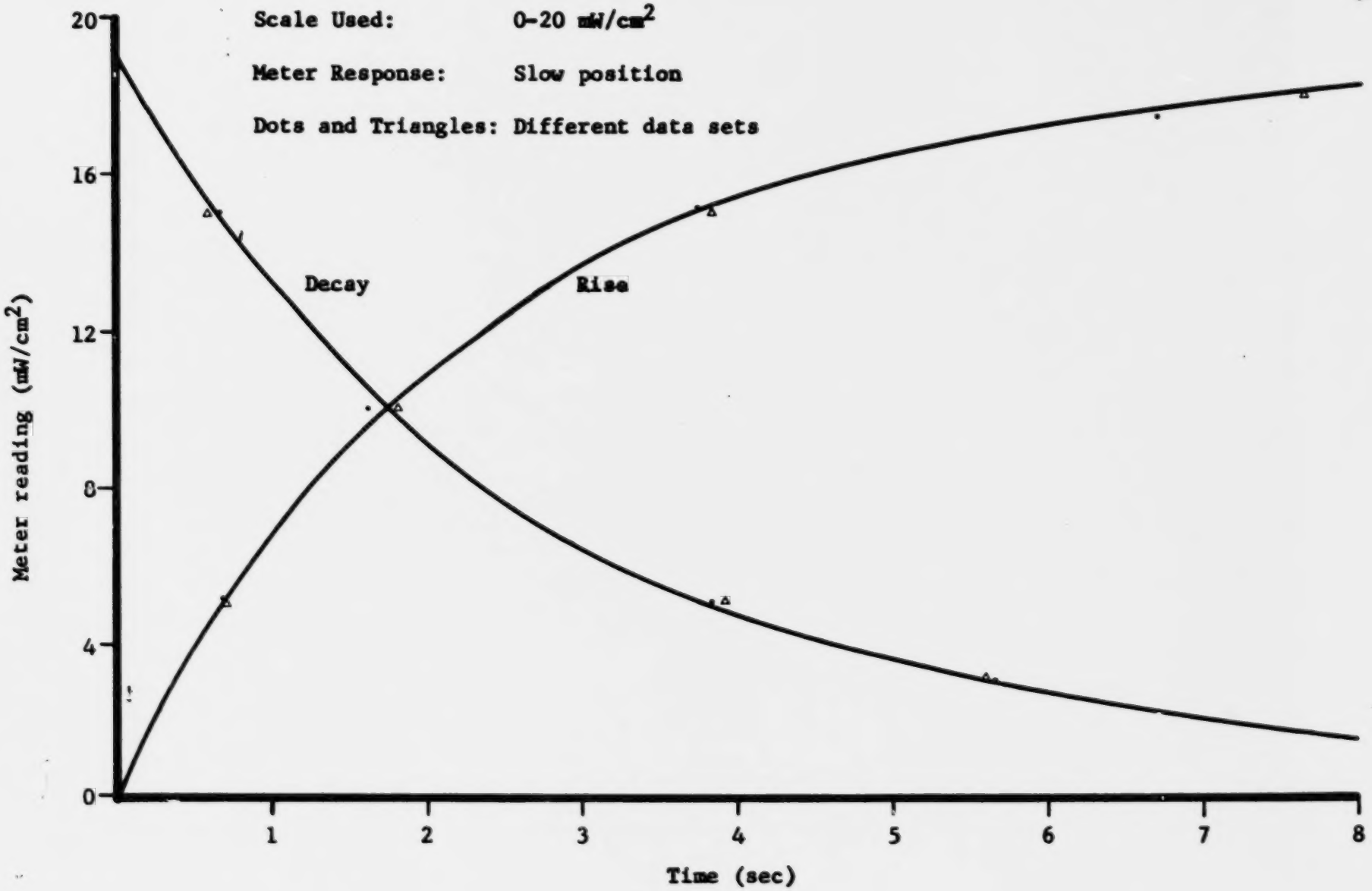


Figure 3. Slow response of Narda 8100 to stepped RF input, Model 8110-8122 combination.

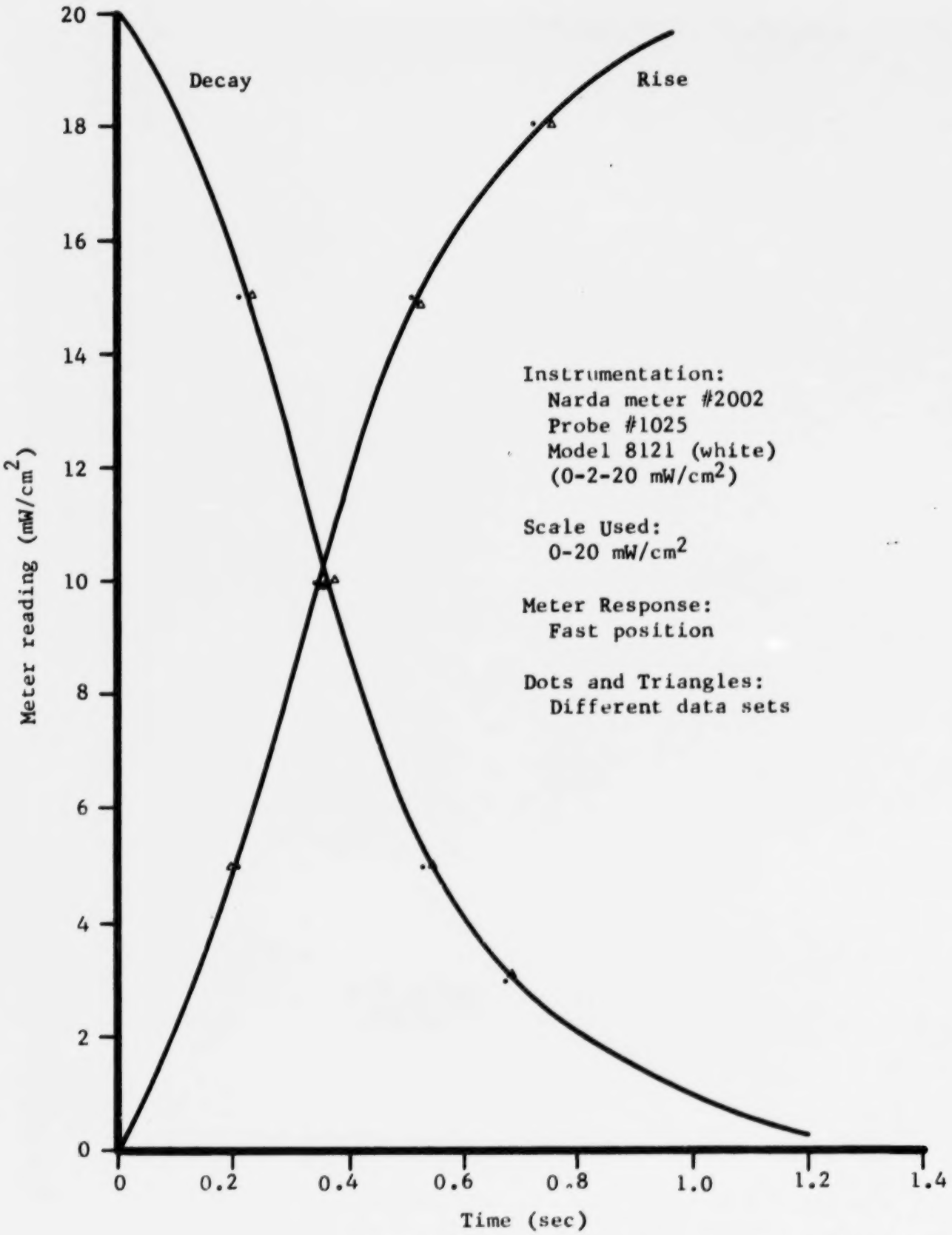


Figure 4. Fast response of Narda 8100 to stepped RF input, Model 8110-8121 combination.

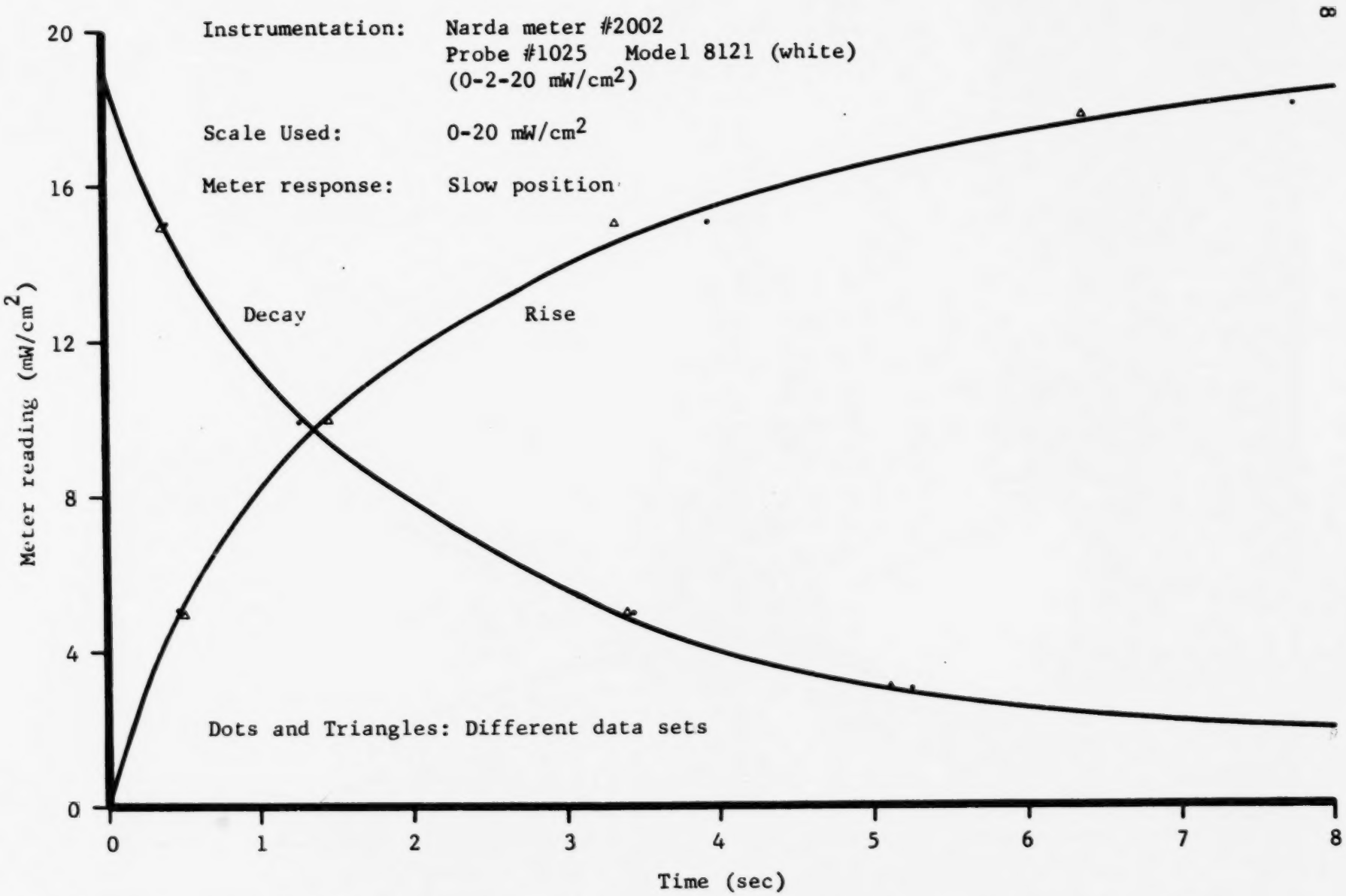


Figure 5. Slow response of Narda 8100 to stepped RF input, Model 8110-8121 combination.

RESULTS

The results are presented in figures 2 and 3 for Narda 8100 system using a model 8122 (0-20-200 mW/cm^2) (red) probe, and in figures 4 and 5 for a model 8121 (0-2-20 mW/cm^2) (white) probe. No significant difference was noted among probes of the same model number. A comparison of figures 2 and 4 shows that the white probe responds faster than the red for identical inputs.

Figure 2 shows that the rise or decay of the meter reading as a function of time is not a simple exponential function, i.e., the meter reading does not appear to fit a function such as:

$$M = M_o (1-e^{-\frac{t}{T}})$$

where M_o is the maximum meter reading, t is time and T is the time constant of the system. This indicates that more than one time constant is involved in the system. One could define an approximate time constant for the system from the above equation by finding the time required to reach the value $M = M_o (1-e^{-1}) = 0.6\ M$. For the case of figure 4 this would be about 0.6 second. Another method of calculating T is to note that the slope of the above equation is given by:

$$\frac{dM}{dt} = \frac{M_o}{T} e^{-\frac{t}{T}}$$

Thus, at t = 0:

$$\frac{dM}{dt} = \frac{M_o}{T}$$

From the initial slope of figure 4 an approximate time constant of 1 second is obtained.

The ambiguity of the term "time constant" for a complex system is obvious. A more suitable and easily defined term would be the response time of the system. The response time can be defined as the

time required for the meter to reach 90 percent of the final value after the onset of a stepped input.

The data presented in table 1 are for one instrument using a single red probe and one white probe only. However, these data are believed to be representative of the general group of probes and instruments.

Table 1. Data for the response of the Narda system.

	Fast response switch setting		Slow response switch setting	
	Time to rise to 90% final (sec)	Time to fall to 10% of max. (sec)	Time to rise to 90% final (sec)	Time to fall to 10% of max. (sec)
Red Probe Model 8122	1.15	1.3	6.3	7
White Probe Model 8121	0.73	0.82	6	7

These data indicate that the response time of the probe and electronic circuitry is the determining factor in the overall response time as well as the meter movement. This is borne out by a comparison of the different results obtained for the two different model probes. For the slow response the electronic circuitry is the limiting factor and the curves of figures 3 and 5 are exponential.

It is also noted that the rise and decay times are approximately equal in all cases. Such a response characteristic is good design and will cause the instrument to give a better average value for rapidly varying power densities.

EFFECT OF MODE STIRRING ON RADIATED POWER DENSITY

In order to perform uniform cooking within an oven cavity, a method of changing the cavity characteristics must be provided. A fan or rotating table is usually provided to prevent or minimize the standing wave which would cause nonuniform heating. This mode stirring which purposely causes variation of the field inside the cavity also causes variations in fields radiated as leakage from the vicinity of the oven door.

Some oven manufacturers provide no mode stirring. It is felt by the manufacturers that the 120 Hz variations from the unregulated power supply provide mode variation for uniform heating. Figure 6 shows the radiated leakage from such an oven as a function of time. The zero time in this figure, as in all other figures in this report, is arbitrary. The delay between zero time and signal onset indicates that the recorder was turned on before the oven magnetron.

The initial periodic variations in the radiated field shown in figure 6 result from oscillation of the water load. Radiation from an oven with a very slow stirrer is shown in figure 7. This oven rotates the food or load rather than using a fan. From figure 7 it is observed that the table rotates about once every eight seconds. The load used in this particular case was 275 ml of water placed away from the center of the turntable. The fast meter response was used when taking these data. The large peaks would not have been observed if the slow meter response had been used (see figures 1a and 1b). Figures 8 and 9 show the effects of more rapid stirrer motion. The fan of figure 8 makes about six revolutions per second. The average and peak meter readings are very close to the same value. It is possible that the variations about the mean are actually larger in these two examples, but they are not observed due to the response of the instrumentation used.

EFFECT OF RESPONSE TIMES ON LEAKAGE MEASUREMENTS

Instrument systems whose response times are long compared to the duration of a transient phenomena being observed record a time average value of that phenomena. An example of this instrumentation

effect is presented in figure 10 in which leakage from an oven was measured with a Narda 8100 using a fast response setting, then repeating the measurement with a slow response setting.

These data were obtained by mounting a Narda probe at a fixed leakage point on the front of an oven. The recorder output of the Narda 8100 was connected to a Moseley model 2D2 x-y recorder. The data were not taken visually and are independent of the meter movement of the 8100. Data presented in figure 10 were for an oven which uses a fan stirrer. Differences in average values for the two response settings are small. Data presented in figure 11 for a different oven also demonstrate this point. Again, the average values are approximately equal, but the variations about the mean are considerably reduced where the slow response is used. As the variation due to mode stirring or other source fluctuation becomes more rapid, the recorded data become limited by the measuring system. Thus, the system begins to present average results rather than actual variations.

Figure 12 demonstrates dramatically the effect of instrument response time on the measurement of oven leakage. Again, this is a recorder output response and is independent of meter movement. Using the fast response the Narda system requires about one second to reach values corresponding to the oven's true output. Using the slow response, about six seconds are required to reach values corresponding to the true oven output. Note that the final average value of the two curves after the six-second time interval is about the same. However, the variation about the mean using the slow response is reduced. The variations about the mean are caused by the mode stirrer.

The difference in the effect of slow and fast response times on measured leakage from an oven with no mode stirrer is presented in figure 13. Again, a five-second difference in the overall response time is noted.

VISUAL AVERAGING OVER A 30-SECOND TIME PERIOD

It has been suggested by the Association of Home Appliance Manufacturers that a proper method of oven testing is to take data over a 30-second time interval and to obtain the root-mean-square of this data. Such a method is impractical for three reasons.

1. Undue hardship is placed upon the operator -For an operator to hold a probe at a single spot in front of an oven and record a significant number of readings over a 30-second period would be difficult. The amount of time needed to record data from a single oven and calculate the RMS value of each set of data would be on the order

Instrumentation:	Narda meter Model 8110 Probe Model 8122
Measurement position:	Maximum along edge of door
Type oven:	No mode stirring
Test:	Fabricated test condition for easy detection of level
Meter Response:	Fast position

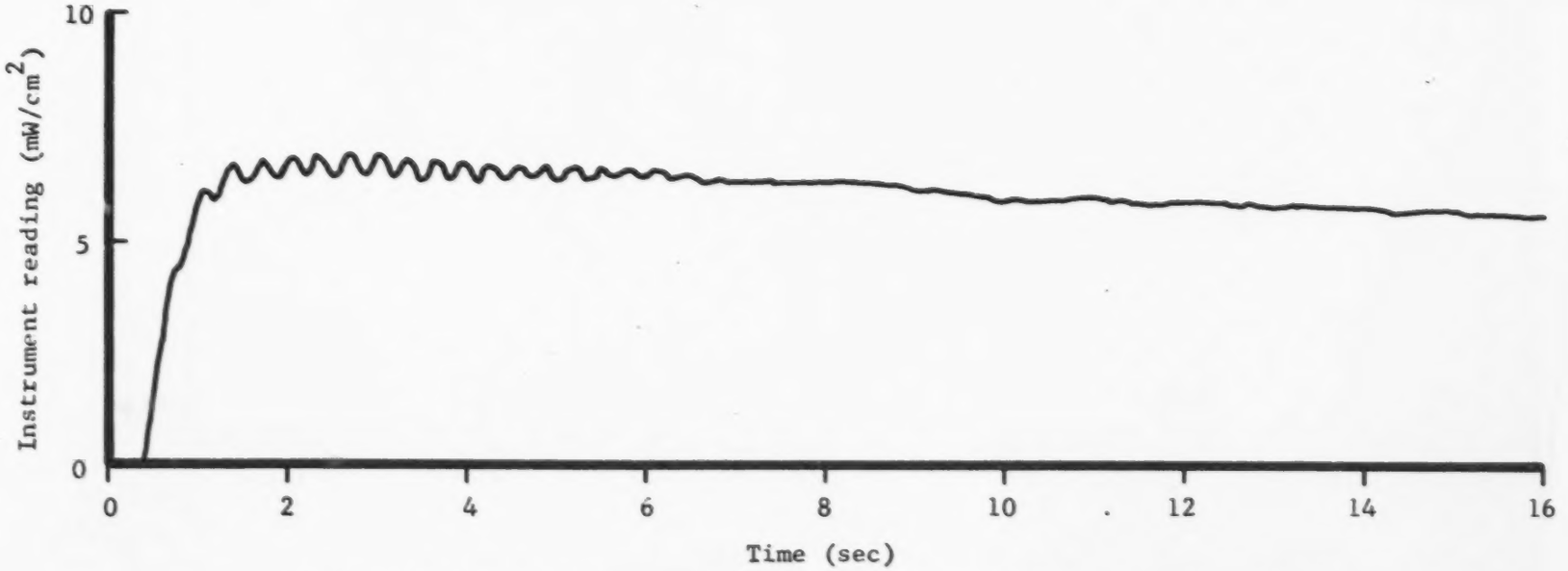


Figure 6. Instrument reading as a function of time: no mode stirring.

Instrumentation: Narda meter Model 8110
Probe Model 8122

Measurement position: Maximum along edge of door

Type oven: Food rotated on turntable (slow stirring)

Meter Response: Fast position

Test: Fabricated test condition for easy detection of level

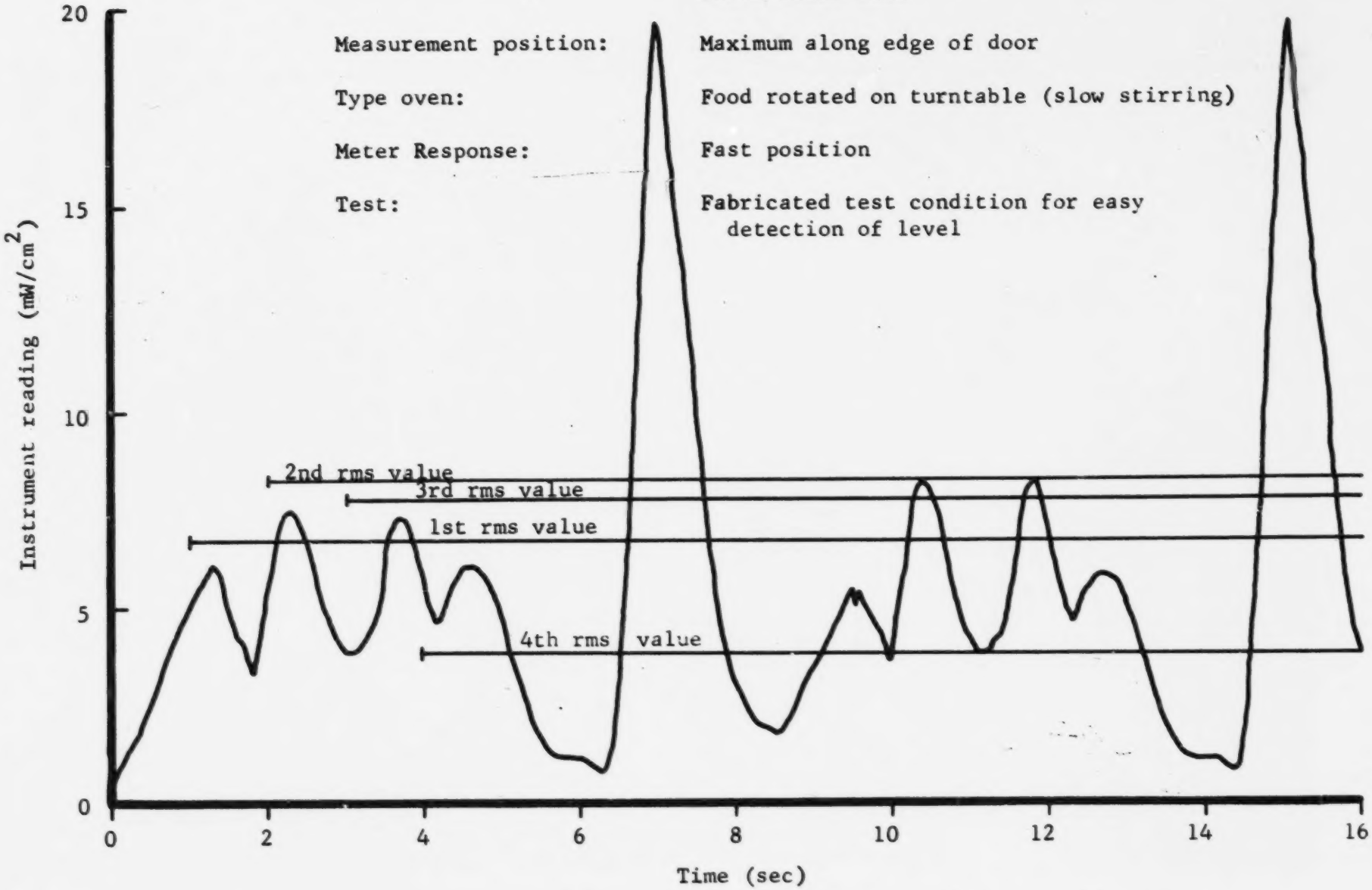


Figure 7. Instrument reading as a function of time: slow turntable stirrer.

Instrumentation:	Narda meter Model 8110 Probe Model 8122
Measurement position:	Maximum along edge of door
Type oven:	Medium fast (fan stirrer)
Test:	Fabricated test condition for easy detection of level
Meter response:	Fast position

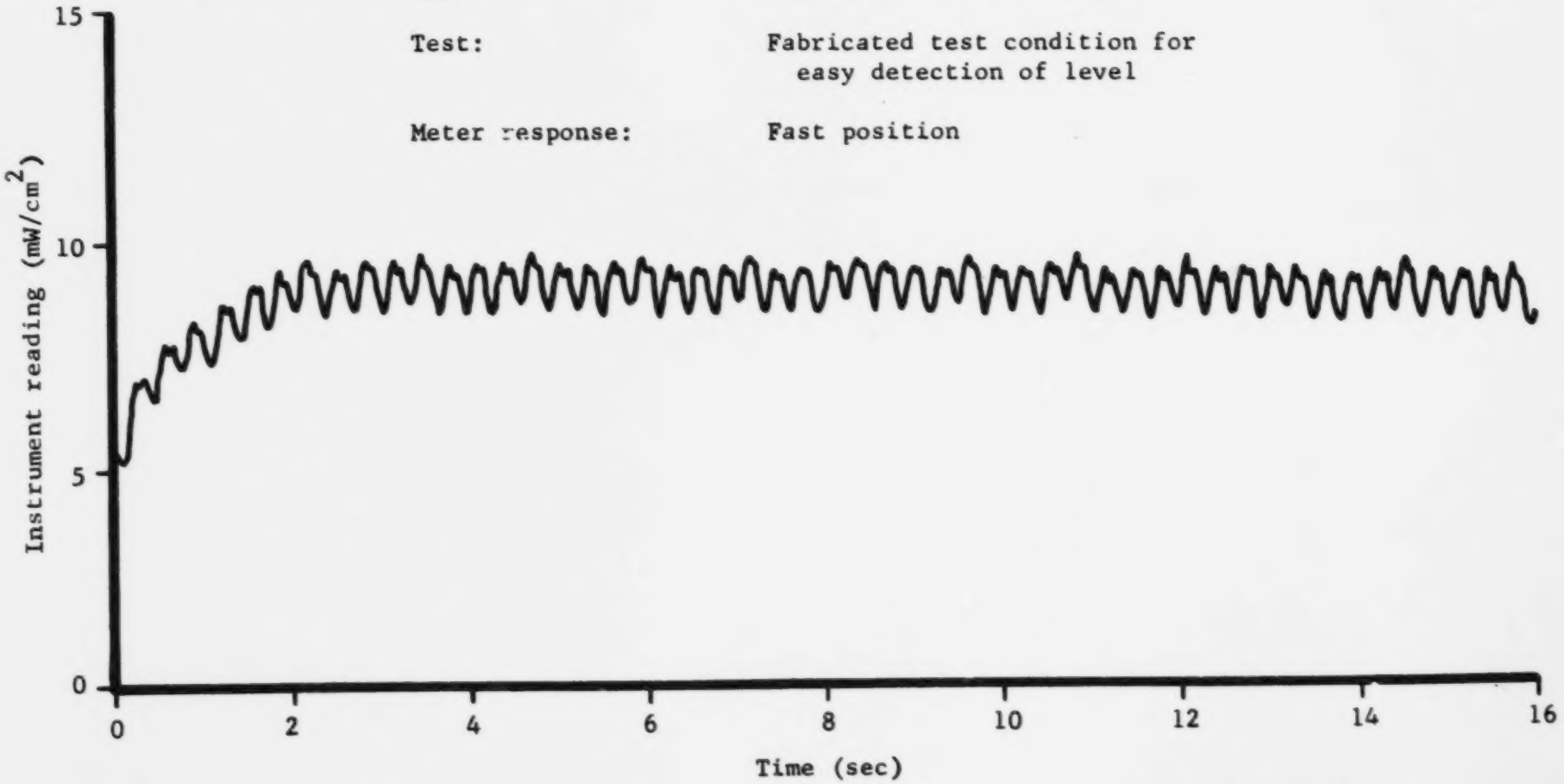


Figure 8. Instrument reading as a function of time: medium-fast fan stirrer.

Instrumentation: Narda meter Model 8110
Probe Model 8120

Measurement position: Maximum along edge of door

Type oven: Rapid (fan stirrer)

Test: Fabricated test condition for easy detection of level

Meter Response: Fast position

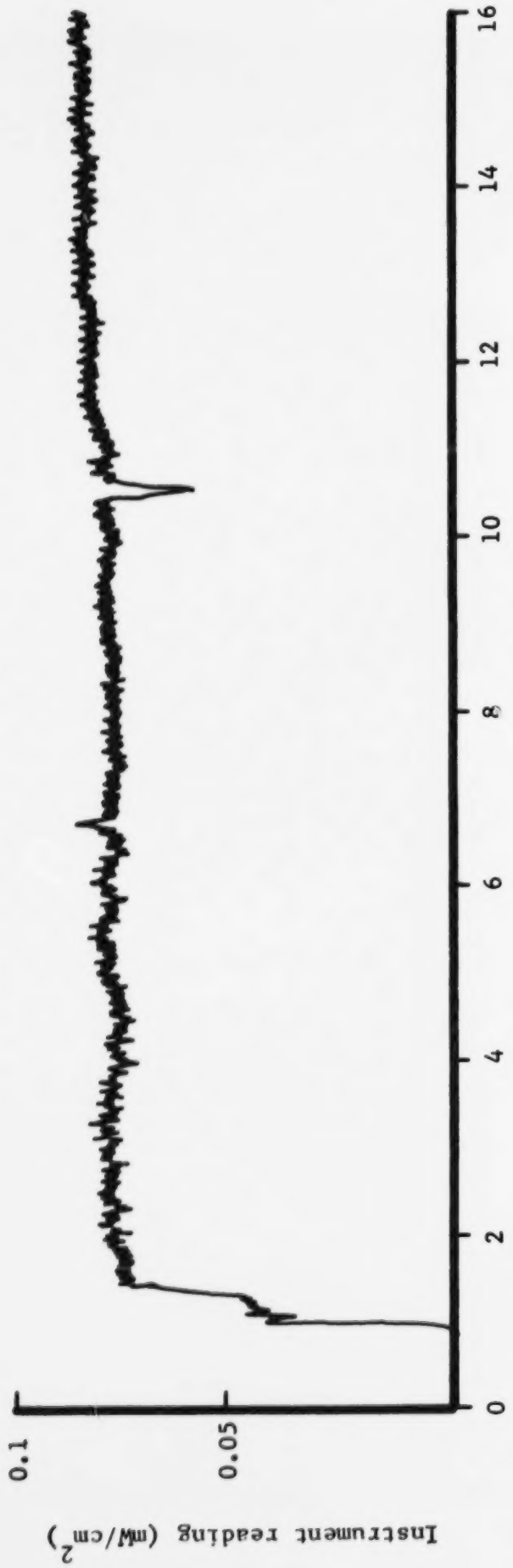


Figure 9. Instrument reading as a function of time: rapid fan stirrer.

Instrumentation:	Narda meter Model 8110 Probe Model 8120
Measurement position:	Maximum along edge of door
Type oven:	Double magnetron and double fan stirrer
Test:	Fabricated test condition for easy detection of level

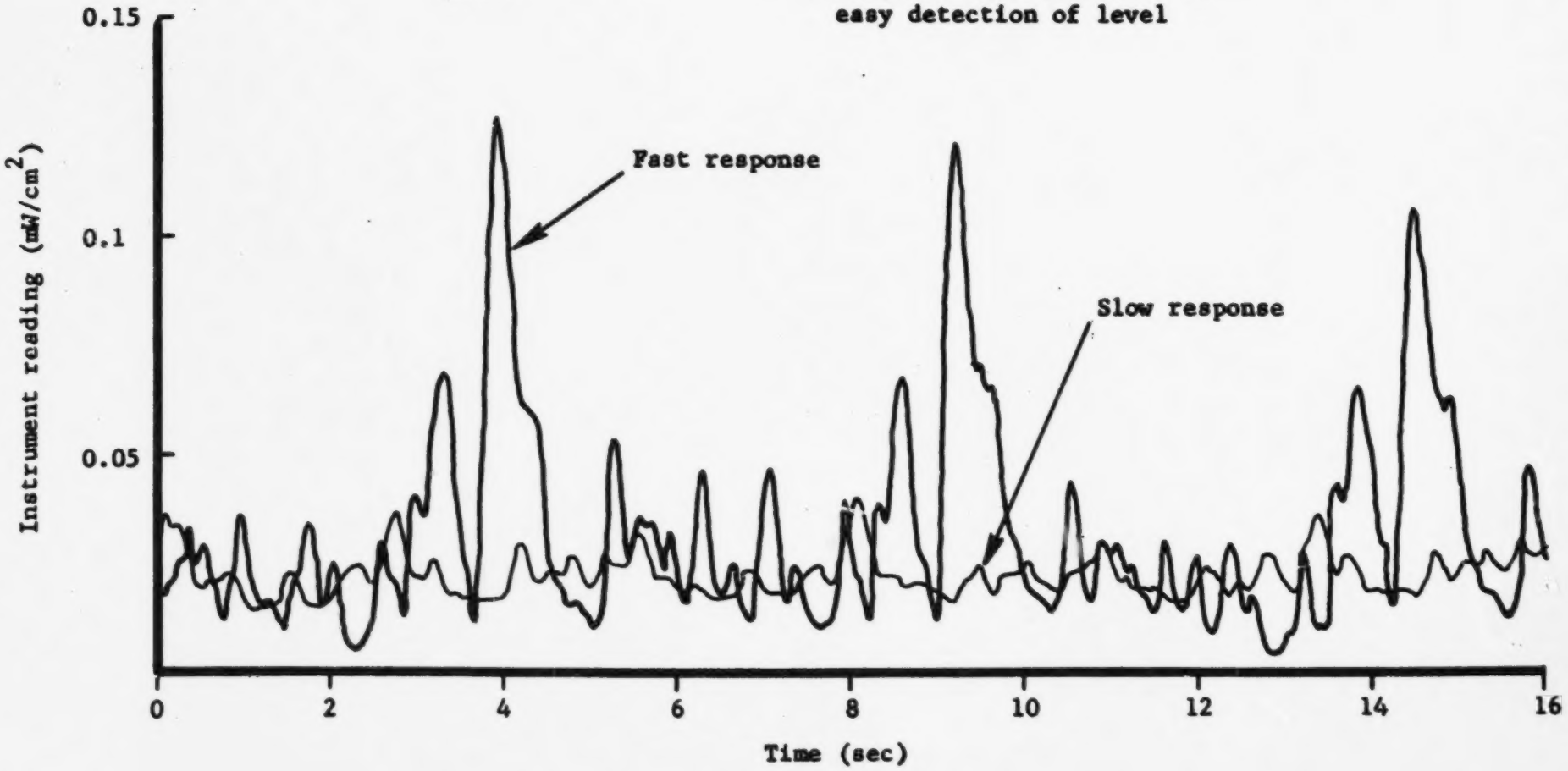


Figure 10. Instrument reading as a function of time (fast and slow response): double fan stirrer.

Instrumentation: Narda meter Model 8110
Probe Model 8122

Measurement position: Maximum along edge of door

Type oven: Rotation of food on turntable

Test: Fabricated test condition for easy detection of level

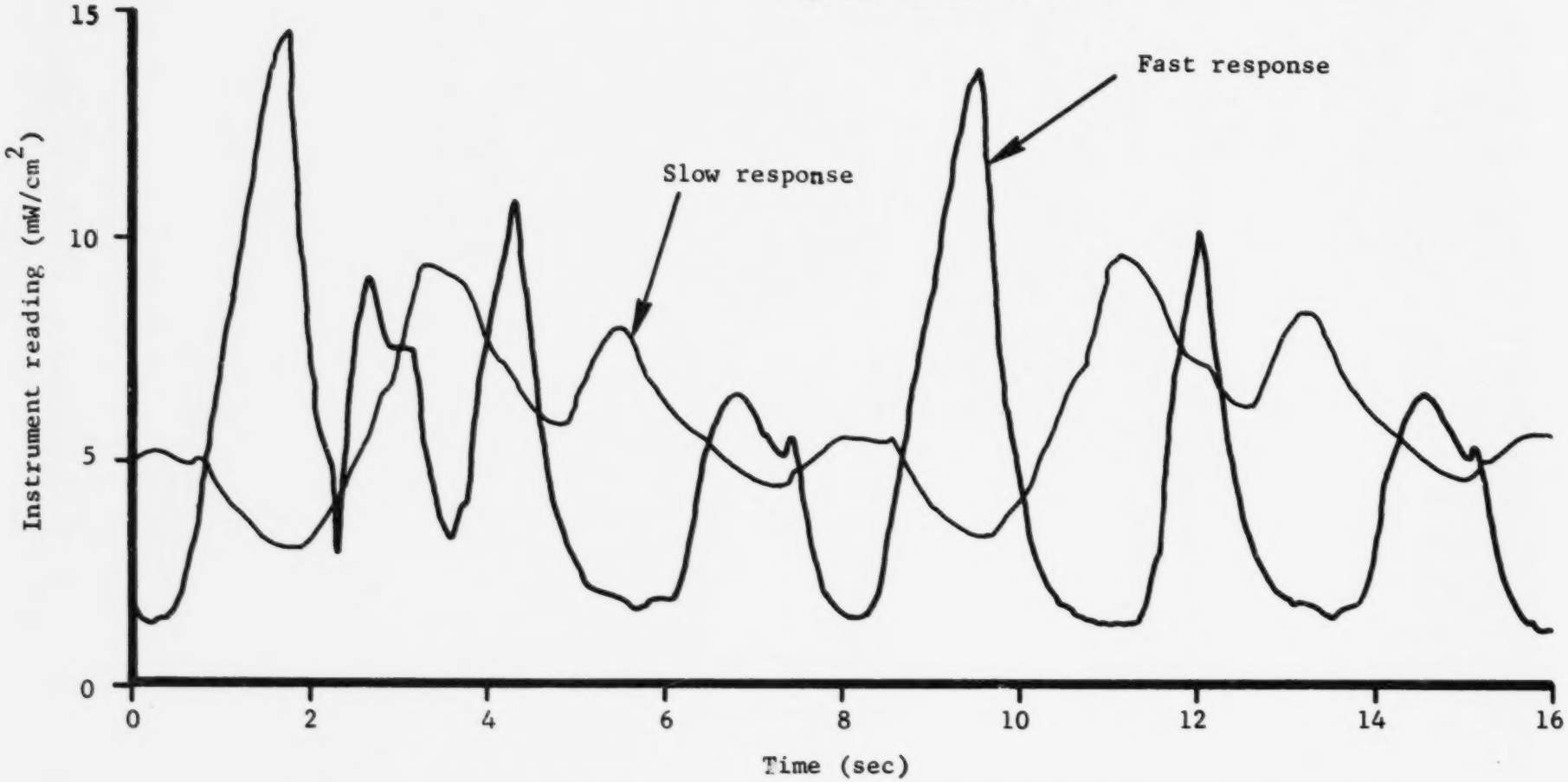


Figure 11. Instrument reading as a function of time (fast and slow response): turntable stirrer.

Instrumentation: Narda meter Model 8110
Probe Model 8120

Measurement position: Maximum along edge of door

Type oven: Fan stirrer

Test: Fabricated test condition for easy detection of level

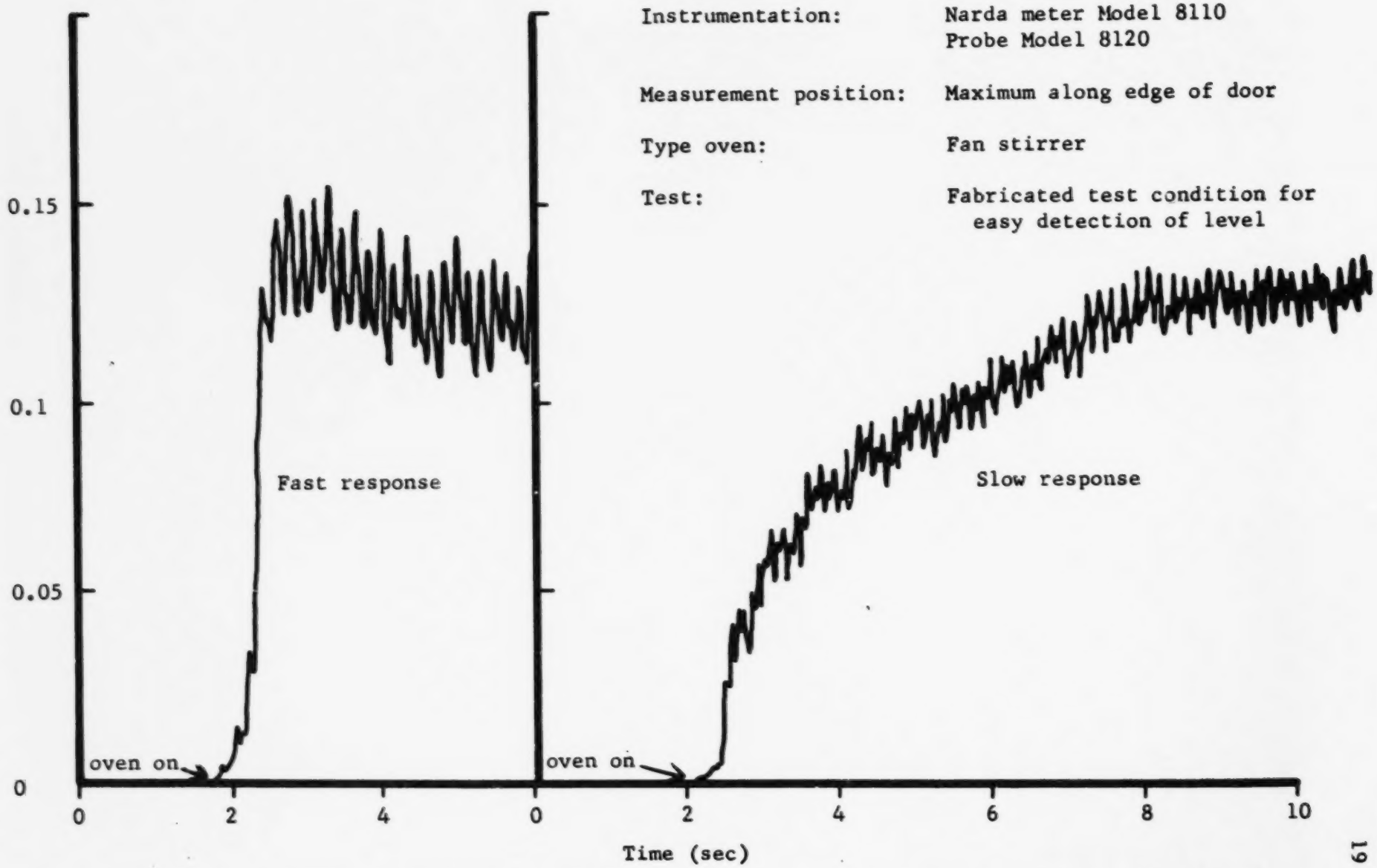


Figure 12. Instrument reading as a function of time (fast and slow response): fan stirrer.

Instrumentation: Narda meter Model 8110
Probe Model 8121

Measurement position: Maximum along edge of door

Type oven: No mode stirring

Test: Fabricated test condition for easy detection of level

Meter Response: Fast position

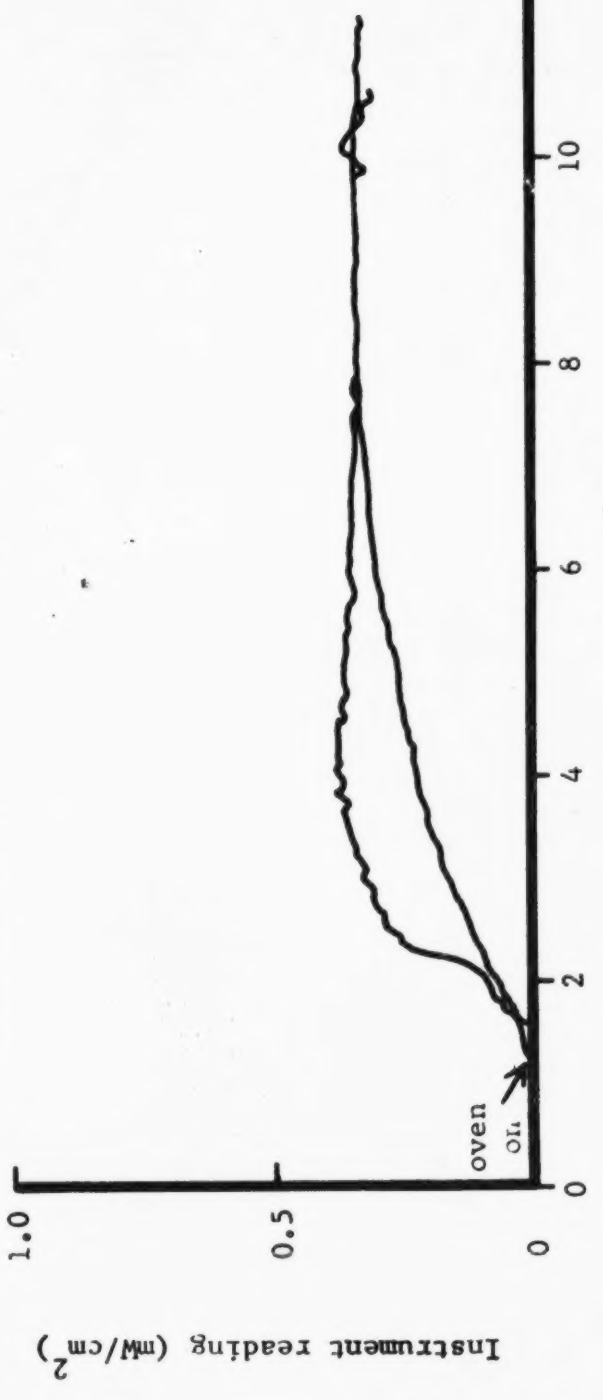


Figure 13. Instrument reading as a function of time (fast and slow response): no mode stirrer.

of several hours. Such an operation would be time consuming. Further, such a measurement method could cause a monitor to expose himself to potentially hazardous radiation. A method of averaging data at "hot spots" only would reduce the time required but not the difficulty of obtaining an average of the data.

2. Meaningful results cannot be obtained -Field survey measurement would be difficult if a recorder were used, therefore, visual data must be taken. For an oven without a stirrer or with a rapid stirrer, the meter readings remain fairly constant and would therefore be fairly easy to record over a 30-second time period. The results would not be ambiguous. For a slow stirrer such as that presented in figure 7, meaningful results would be at best difficult to obtain. True random selections of points over the 30-second interval would require the use of automated recording equipment.

A meter with a long response time places hardship on the operator and increases the oven operation time required for the testing procedure. The operator must be able to hold the measuring device in a fixed position for a length of time which is at least equal to the rise time of the meter before measurements can be taken. It should be pointed out that the measurements taken in this report were with the probe mounted in a permanent position and not hand held. This is a laboratory condition and not indicative of field operations. Variation in probe position would affect the average value. Fast response times increase the ease and accuracy of measurements as well as allow the operator to obtain a true reading of the peak power emitted from the source.

As an example of the ambiguity of such a technique, data were selected from figure 7 at regular intervals. An arbitrary starting point was chosen and data were taken from the graph at 5-second intervals over a 30-second time period. The RMS value and the mean value for four different starting points are listed in table 2.

Table 2. Averaging of power density readings of oven leakage.

Peak Value	Start of data collection	Average mW/cm^2	RMS mW/cm^2
19.8 mW/cm^2	1st	5.63	6.79
	2nd	5.9	8.38
	3rd	6.19	7.87
	4th	3.67	3.89

Note that the RMS values vary by more than a factor or two. A single RMS or mean value gives no indication of the variations over the 30-second time period. The fact that a peak reading of 19.8 mW/cm^2 was recorded would be totally ignored in an averaging type of measurement technique.

3. <u>The RMS value of the power density will not be a valid description of the physical event</u> -It has been noted that the meter tends to read the average value as the response time is increased. Thus, the average is the physically meaningful quantity and not the RMS value. If one were measuring voltage or field strength, RMS values might be an appropriate way of relating the latter values to a power density calculation.

It has been further suggested that the use of a tape recorder and stop watch would aid in the taking of an average value over the 30-second time period. The tape recorder would allow one to take 15 readings at regular intervals or one every two seconds. In order to obtain the possible extremes of such a method, average values were obtained from figure 7. Values ranging from 3.85 mW/cm^2 (by starting at a minimum of the curve) to 8.08 mW/cm^2 (by starting on a peak) were obtained.

Techniques which allow variation of 10 percent would in most cases be acceptable. However, variations of 2 to 1 for measurement concerned with human health are most unacceptable. A meaningful average would be difficult to obtain.

CONCLUSIONS

Any averaging time other than an internal instrument averaging time creates difficulty with survey procedures and does not necessarily relate to physically meaningful measurements. The response of an instrument system determines whether or not the reading is a maximum or average value. The Narda 8100, when used in the fast response setting, gives an accurate representation of power density variations from ovens using slow stirrer speeds. As the mode stirring frequency is increased so that fluctuations in the radiated field occur in less than one second, the Narda 8100 will no longer indicate maximum values but will begin to show reduced variations about the average.

Procedures should be established as guides to the surveyor so that a proper amount of data will be taken to determine compliance. These procedures should only be guides and not limitations on the methods and amount of data taken by the operator or surveyor.

APPENDIX A

RECOMMENDED PROCEDURE FOR USE OF NARDA 8100 IN OVEN SURVEY

1. Make sure oven is off.

2. Turn Narda 8100 on and allow a short period of time for warm-up (about 30 seconds). The meter usually drifts for the first few seconds.

3. Check battery and probe for proper operation.

4. Select proper frequency position (915 MHz or 2450 MHz) for source being surveyed.

5. Set meter response on FAST position.

6. Set range on 0-20 mW/cm^2 scale using red probe. (White or middle range probe may be used but this probe is more susceptible to burn out than the higher range or red probe.)

7. Set zero adjust.

8. Turn (oven) power source on.

9. Stand a few feet away from oven or source and determine whether leakage above 20 mW/cm^2 is being emitted. If leakage about 20 mW/cm^2 is being emitted, proceed rapidly and with caution. Stand as far away from oven as possible during survey. Ovens with this much leakage should be surveyed in a matter of seconds and turned off. If leakage below 20 mW/cm^2 is being emitted, change to 0-20 mW/cm^2 scale and proceed with survey.

10. For normal survey the probe with the appropriate 5-cm space should be moved slowly along the seal of the oven door. A "sweep" across the top of the oven door should take about five seconds. When a hot spot is located the surveyor should stop and observe readings for one stirrer cycle. This time will vary for the different types of ovens and may be as long as eight seconds.

11. All possible points of leakage such as door seals, door view screens, and vents should be checked.

12. Record peak readings observed.

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